CHAPTER 2

STORMWATER MANAGEMENT and URBAN BMPs

TABLE OF CONTENTS

#	SECTIONS	PAGE
2-1	COMPONENTS of STORMWATER MANAGEMENT	2-1
	2-1.1 Water Quality	2-1
	2-1.2 Stream Channel Erosion	2-2
	2-1.3 Flooding	2-3
	2-1.4 Regional (watershed-wide) Stormwater Plans	2-3
2-2	BMP SIZING CRITERIA	2-4
	2-2.1 Water Quality	2-4
	2-2.2 Stream Channel Erosion	2-8
	2-2.3 Flooding	2-10
	2-2.4 More Stringent Criteria	2-10
2-3	BMP SELECTION CRITERIA	2-11
	2-3.1 Site Feasibility	2-12
	2-3.2 Site or Watershed Stormwater Management Requirements	2-14
	2-3.3 Technology-Based and Performance-Based Water Quality Criteria	2-19
2-4	REGIONAL STORMWATER MANAGEMENT PLANS	2-26
2-5	COMPREHENSIVE WATERSHED MANAGEMENT	2-30
	2-5.1 Inventory of Watershed Characteristics	2-32
	2-5.2 Planning and Developing the Watershed Management Plan	2-38
	2-5.3 Implementation of the Watershed Management Plan	2-40

LIST OF ILLUSTRATIONS

#	FIGURES	PAGE
2-1	Removal Rate vs. Detention Time for Selected Pollutants	2-5

#	TABLES	PAGE
2-1	Pollutant Removal Mechanisms	2-6
2-2	Functional Goal of Stormwater BMPs	2-17
2-3	Target Phosphorus Removal Efficiency	2-18
2-4	Classification of Urban Hotspots	2-19

2-1 COMPONENTS OF STORMWATER MANAGEMENT

The goal of storm water management is to mitigate the impact on the hydrologic cycle resulting from changes to the land surface. Urban development has been identified as having a direct impact on the hydrologic cycle by reducing or even eliminating the natural storage capacity of the land. This impact is the result of a decrease in tree cover, loose organic surface soils, and natural depressions, all of which provide natural storage capacity. These natural storage areas are then replaced with impervious and managed pervious surfaces. Impervious cover prevents the percolation of the runoff into the soil, which means that most, if not all of the rainfall is converted to runoff. In addition, managed pervious areas, such as courtyards and lawn areas typically do not provide opportunities for infiltration due to compaction of the surface soil profile and improved drainage conveyances. (The impact of development on the hydrologic cycle is discussed in detail in **Chapter 4; Hydrologic Methods**.) The results of increased stormwater runoff can be classified by its impact on *water quality*, *stream channel erosion*, and *localized flooding*. These components are identified in the Virginia Stormwater Management (SWM) Regulations.

2-1.1 Water Quality

One of the impacts of stormwater runoff is that of the quality of the runoff on the aquatic ecosystem. Various soluble and particulate pollutants are found in stormwater runoff. Studies have shown that the source of these pollutants are atmospheric deposition, urban and agricultural lands, and natural spaces. The focus of this document is on the urban land sources. The impervious surfaces, such as parking lots, roof tops, roads, etc., which are associated with land development serve to accumulate and transport these pollutants to receiving stream channels. It should be noted that pervious areas associated with development, such as golf courses, parks, open space, etc., also contribute pollutants.

The following presents a basic overview of the typical urban pollutants. Additional discussion of urban pollutants associated with certain ultra-urban development environments, referred to as *stormwater hotspots* (Claytor, 1996) is discussed in **Section 2-3: BMP Selection Criteria**.

Nutrients. Concentrations of nutrients, such as nitrogen and phosphorus, found in urban runoff can cause eutrophication of receiving streams, lakes, and rivers, and estuaries. As these nutrients collect in slower moving water bodies, they promote the growth of algae, which in turn blocks sunlight to bottom grasses, and eventually leads to a depletion of available dissolved oxygen (DO). Nutrients in urban runoff have been identified as being a significant contributor to the decline of the Chesapeake Bay. The Virginia Tributary Strategy initiative calls for a 40% reduction in nutrients reaching the Chesapeake Bay by the year 2000.

Suspended solids. All natural drainage channels have a natural sediment bed load which helps maintain a state of equilibrium within the channels of undeveloped watersheds. Increases in the peak rates of flow through the channel or stream system will disrupt the equilibrium by increasing the amount of sediment removed from the channel bed and banks. Suspended solids which result from excessive erosion and scour of the stream channel, the transport of sediments from impervious and managed pervious surfaces, and construction site runoff can have many adverse impacts on aquatic life throughout the water column. Further, these sediments will eventually settle in slower waters and smother the benthic habitat.

The "shock loading" which results from construction site runoff is most damaging to the aquatic habitat. The Virginia Erosion and Sediment Control Program addresses construction site runoff with the implementation of temporary erosion and sediment control measures specifically designed to inhibit sediment from leaving the site, as well as specifications for stabilization of the site once construction is complete. Even after final stabilization, however, loose soil or worn areas will continue to be a source of sediment to the receiving streams.

Bacteria. Varying levels of bacteria found in surface stormwater runoff can create public health concerns in receiving streams and lakes. The source of bacteria in stormwater runoff includes livestock operations, failing septic systems, unusually high concentrations of pet and wildlife droppings, leaking sewer lines, illicit connections between storm and sanitary lines, combined sewer overflows, etc. High concentrations of bacteria often result in the closure of public recreational uses of water resources, and may increase the cost of treatment for domestic water use.

Hydrocarbons. Hydrocarbon loading in urban runoff is often associated with automobile engine oil, lubricants, and other compounds. Hydrocarbon levels have been found to be highest in the runoff from parking lots, roads, and service stations.

Trace metals. Trace metals found in urban runoff, such as cadmium, copper, lead, and zinc, originate from a wide variety of sources such as roofing materials, down spouts, galvanized pipes, catalytic converters, brake linings, etc. Over time these surfaces wear down, enabling the metals to wash away in urban runoff.

Biological Oxygen Demand (BOD). Decomposition of organic matter in slow moving receiving water bodies such as lakes and estuaries increases the biological oxygen demand. High BOD depletes the available dissolved oxygen (DO) necessary to sustain aquatic life.

Thermal Impacts. Runoff from urban impervious surfaces can significantly increase ambient temperatures in receiving streams. Paved surfaces transfer significant amounts of thermal energy to runoff passing over it. When this warmed runoff reaches the receiving stream, a rise in temperature of just a few degrees can have a adverse impact on aquatic life.

2-1.2 Stream Channel Erosion

The impact of increased stormwater runoff can be easily observed in an urbanized stream system. Most of the drainage network is developed or improved to convey increased volumes and rates of runoff to the receiving stream channel. The stream channel then responds to the increase in flow by eroding to form a larger cross sectional flow area which, theoretically, should result in reduced flow velocities. An eroded channel, however, is quite often a very efficient conveyance system and promotes an even faster velocity of flow, which in turn, accelerates the channel erosion process. Once this process has begun, it is very difficult to stop because typical stream channel soils are highly erodible once the protective lining of cobble or vegetation is eroded away.

2-1.3 Flooding

When the rate of stormwater runoff exceeds the capacity of the various manmade or natural conveyance systems, the result is localized flooding. The conveyance system gradually catches up and drains the flood waters as the rainfall subsides. In some cases debris or other materials dislodged by the rising flood waters will clog the drainage system and cause longer periods of flooding. In either case, pockets of standing water which do not drain will remain for periods of time and eventually percolate into the ground or evaporate.

In the pre-developed condition, most stream channels have an adequate floodplain or flood fringe to convey and store the out of bank flows with minimal damage. With urbanization, however, these floodplain areas are often eliminated or developed with improvements. The periodic ponding of water in developed areas often results in damage. Pavement will fail or be undermined, structures will be water damaged, landscaping and other improvements not used to inundation will be damaged.

2-1.4 Regional (watershed-wide) Stormwater Plans

The cumulative effect of sedimentation, scouring, increased flooding, lower summer flows, higher water temperature, and pollution contribute to the overall degradation of the stream ecosystem. Many studies have documented the decline of fish diversity in urbanized watersheds. The aquatic insects which are a major food resource for fish are impacted by the increased sediment load, trace metals, nutrients, and flow velocities. Less noticeable impacts to the stream systems are changes in water temperature, oxygen levels, and substrate composition.

A regional or watershed-wide stormwater plan provides the framework needed to evaluate the impacts of changes to the land on water resources. A comprehensive watershed management plan considers all of the impacts of increased stormwater runoff: water quality, channel erosion, and flooding. The plan is the result of studying the environmental features of the watershed to identify those areas that should be protected and preserved. The plan identifies and strategically locates stormwater management measures and design criteria to be utilized to protect the watershed. The plan also aims to utilize and protect ecological processes to lessen the need for structural control methods that require capital costs and maintenance.

2-2 BMP SIZING CRITERIA

Stormwater management policies have been developed over the years in an attempt to mitigate the impact of land development on aquatic systems as discussed previously. Increased flash flooding and the associated flood damage in urbanizing areas gave rise to stormwater management policies based on controlling peak discharge. In addition to the structural damage, significant erosion of the channel bed and banks was considered to be a detriment to the value of property. Detention basins sized to reduce the post-development peak discharge to the pre-developed rates became an acceptable and commonly used method of mitigating these impacts of urbanization. As channels eroded, more and more localities developed peak rate control policies aimed at controlling channel erosion and localized flooding. These policies, however, were still based on a peak rate of discharge and did not address the increased *volume* and *frequency* of the peak discharge.

Both theory and experience indicates that, while detention basins designed to control peak discharge are effective in controlling peak rates, the basins are ineffective in controlling the degradation of erodible channels downstream of the basin. (McCuen, Moglen, 1988). Similarly, detention basin design must incorporate methods for improving water quality. The following discussion provides a discussion of various sizing criterion for stormwater quality, stream channel erosion, and flood control BMPs.

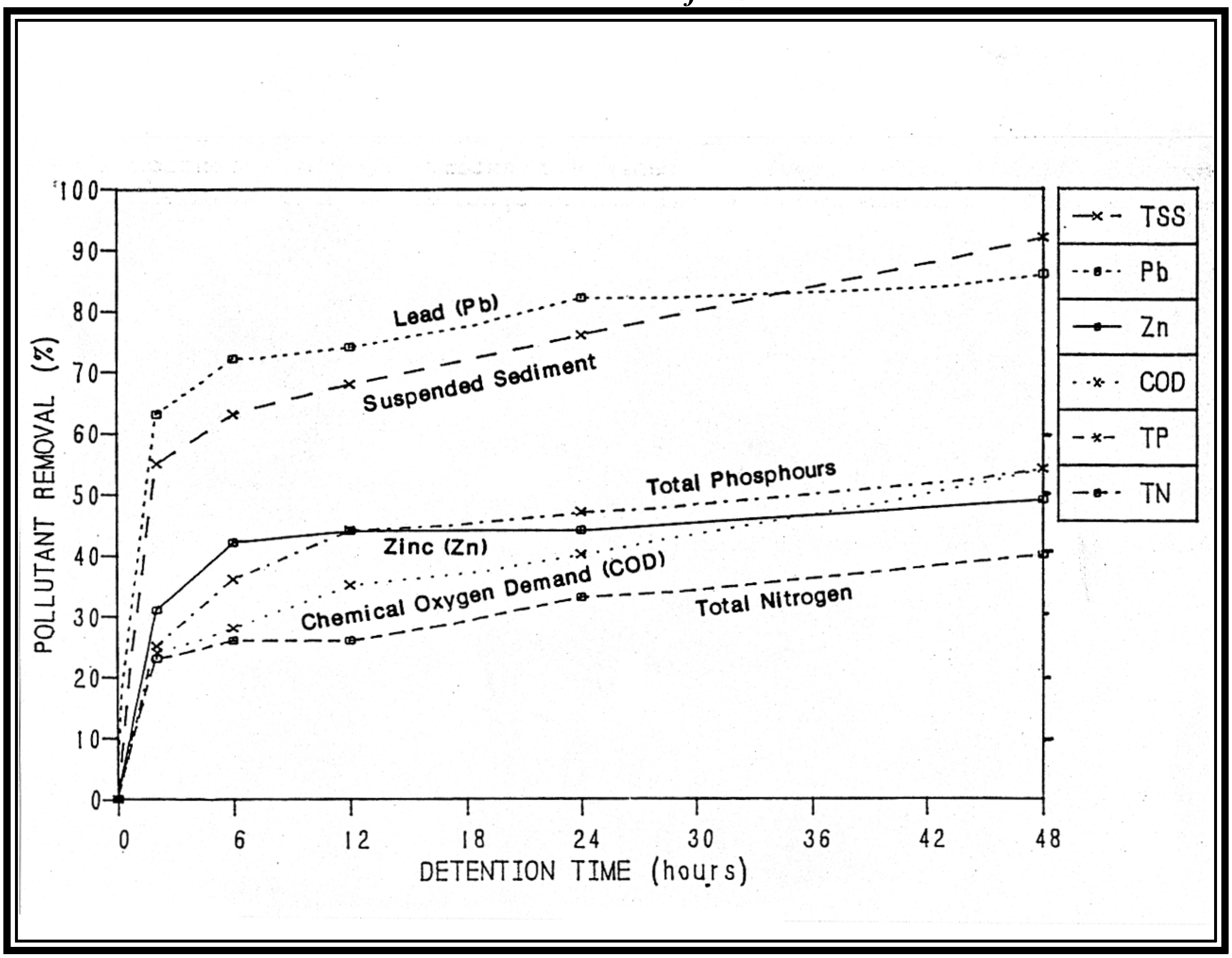
2-2.1 Water Quality

Pollutant Removal Mechanisms

Pollutant removal mechanisms employed by urban BMPs include *settling*, *filtering*, and *biological processes*.

Settling or *sedimentation* is limited to particulate pollutants which drop out of the water column by way of gravitational settling. In some cases, pollutants will attach themselves to heavier sediment particles or suspended solids and drop out of the water column. Laboratory and field studies indicated that significant settling of urban pollutants occurs in the first 6 to 12 hours of detention. **Figure 2-1** provides removal rate vs detention time for selected pollutants. The brim draw down requirement for water quality extended detention design is 30 hours, rather than the minimum of 6 to 12 hours. The additional time is required to allow for ideal settling conditions to develop within the stormwater facility. In addition, the added time will allow for settling of smaller particle sizes and nutrients, as well as increasing the opportunity for biological processes. Stormwater BMPs which utilize settling are usually suited for dual purposes, that is they can also provide storage volume for peak rate control, channel erosion, and/or flood control. These impoundment water quality BMPs are generally sized based on a volume of runoff, commonly referred to as the *water quality volume* (WQV), or "first flush" of runoff. The water quality volume is discussed in detail later in this section.

FIGURE 2-1
Removal Rate vs. Detention Time for Selected Pollutants



Source: Schueler, Controlling Urban Runoff, 1987

Stormwater filtering or *filtration* is typically limited to BMPs which address water quality. These facilities utilize a filter media, such as sand, peat, grass, compost, or various types of fabrics or other material to strain pollutants out of the stormwater. Since the stormwater must pass through the filter media in order to be treated, these structures are limited to small drainage areas (less than 5 acres) and low flow rates. A drawback to these structures is the overflow or bypass of large flows from high intensity storms. The current sizing criteria for these BMPs is the water quality volume. The Department is currently evaluating the option of designating a flow rate or return frequency intensity for design purposes. In most cases a bypass or diversion structure is needed to allow large flows to bypass the BMP without flushing previously deposited pollutants out of the BMP. Guidance on this issue will be provided in the future.

Biological processes are the most effective removal mechanisms for soluble pollutants, such as nutrients. A combination of shallow permanent pool depths and abundant vegetation help to create conditions which allow a natural food chain to develop. Marsh plants, algae and bacteria that grow on the shallow organic rich sediments can take up soluble forms of nutrients needed for their growth. BMPs suited for this pollutant removal mechanism include enhanced extended detention, retention, constructed stormwater wetlands, and in some cases bioretention. The sizing criteria for these BMPs is generally based on permanent pool volume defined as a multiple of the water quality volume, IE: 2.0 or 3.0 times the WQV. (Bioretention utilizes filtering as the primary pollutant removal mechanism.)

Table 2-1 identifies the pollutant removal mechanism utilized by each of the BMPs listed in Table 1 of the Virginia SWM Regulations. It should be noted that the Manufactured BMP Systems are not itemized in **Table 2-1**. For further discussion of Manufactured BMP Systems, refer to **Minimum Standard 3.15**.

TABLE 2-1
Pollutant Removal Mechanisms

Water Quality BMP	Settling	Filtering	Biological
Vegetated filter strip		U	
Grassed swale (w/ check dams)	U	U	
Constructed wetlands	U	U	U
Extended detention	U		
Extended detention enhanced	U	U	U
Bioretention		U	U
Retention basin I, II	U		U
Retention III	U		U
Sand filter		U	
Infiltration		U	

Many stormwater BMPs will utilize a combination of these pollutant removal mechanisms. In some cases, after a BMP has been in operation for a period of time, a layer of organic matter will develop within the BMP, thereby increasing the adsorption potential of the BMP. *Adsorption* is the chemical or molecular attraction which enhances the removal of soluble pollutants. BMPs which include plants and grasses also display increased pollutant removal efficiency over time as the biomass increases. As the vegetation thickens, it serves to slow the velocity of the runoff through the BMP. This allows for increased gravitational settling and filtering of pollutants, as well as decreased export of sediment and attached pollutants via erosion.

Water Quality Volume (WQV)

Ideally, the pollutant removal mechanism should dictate the treatment volume or frequency storm for water quality BMPs. The sizing of BMPs which utilize gravitational settling of pollutants as the removal mechanism can be based on a volume of runoff, while BMPs which utilize filtering should probably be based on a flow rate or frequency. Design criteria provided in **Chapter 3: BMP Minimum Standards**, specifies maximum flow velocities for grass swales and filter strips, as well as the need for a flow splitter or bypass structure for sand filters and other flow through structures.

The Virginia Stormwater Management Regulations require that the *first flush* of runoff be captured and "treated" to remove pollutants. The first flush, or water quality volume (WQV) is generally defined as the first ½" to 1" of runoff from impervious surfaces. Other methods of defining this first flush have been developed. One method in particular, developed by The Center for Watershed Protection, utilizes the Runoff Frequency Spectrum (RFS) for the Washington D.C. area and surrounding Chesapeake Bay watershed. The RFS is based on the fact that 90% of the annual runoff is generated by storms of 1" of rainfall or less. Therefore, the goal of treating at least 90% of the annual runoff results in a treatment volume based on a 1" rainfall. The volume of runoff is determined by multiplying a volumetric runoff coefficient (R_v), based on site imperviousness, by the 1" of rainfall. This method generates a water quality volume of close to 1" for highly impervious sites and gradually decreasing volumes for gradually decreasing levels of imperviousness.

As noted in the Virginia Stormwater Management Regulations, water quality BMPs which are dependent on volume, such as extended detention, constructed stormwater wetlands, and in some cases infiltration, have a required treatment volume of 2.0 x WQV (or 2.0 x 0.5" = 1.0" per impervious acre). This will result in a very similar volume as that based on the RFS method described above. As these methods are studied and BMPs are monitored, the design criteria for determining the WQV may be refined to achieve a greater overall level of treatment.

While the first flush from a storm event is considered to contain the highest concentration of pollutants, there is considerable debate over the intensity of rain needed to wash the pollutants from the urban landscape. Studies have shown that intensity is the critical wash off factor for most storm events, and many people can intuitively comprehend that higher intensity rains leave impervious surfaces cleaner than lower intensity rains. (Adams, 1997). The typical SCS rainfall hyetograph starts with a low rainfall intensity which gradually rises to a peak and then declines. This may indicate that in some cases the designated water quality volume provided in a stormwater basin may fill up with the relatively clean water at the onset of a rain event, consequently allowing the larger flows associated with the high intensity rain and pollutant wash off to pass through the facility.

A similar discussion on the design criteria for water quality structures focuses on the "volume" of runoff verses the "rate", or even the return frequency, of runoff. The water quality volume or first flush is detained in a basin or impoundment structure to allow the pollutants to settle out. Whether that specific volume of runoff enters the basin gradually, or as the result of a sudden high intensity rain, it is still detained for a period of time. Filtering structures, on the other hand, can handle only a certain design flow rate. Sudden high intensity rain will typically generate too much runoff too fast and therefore bypass the treatment facility.

A new category of water quality BMPs: Manufactured BMP Systems (**Minimum Standard 3.15**), utilizes combinations of settling, swirl concentration, and filtering to separate pollutants from the runoff. These structures vary in how they respond to high flows. Some will bypass large flows with little or no treatment, while others will continue to separate and treat the runoff at a reduced efficiency. Further study of these manufactured systems and the appropriate design criteria for flow through or hydro-dynamic structures is warranted and will be provided at a future time.

2-2.2 Stream Channel Erosion

Stream channel erosion results primarily from high scour velocities over extended durations of time. Studies show that natural channels are shaped by the 1½- to 2-year frequency storm event. (Leopold et al., 1964; Anderson, 1970). This frequency allows the channel to maintain a state of equilibrium with regard to the natural sediment load transport and natural vegetation which helps to stabilize channel banks. Therefore, local ordinances have traditionally regulated the 2-year storm, specifying that the post-developed peak rate of runoff may not exceed the pre-developed rate. Note, however, that this requirement does not address the increase in the *frequency* of that peak runoff rate. Urbanization usually increases the amount of impervious cover, resulting in less infiltration, less initial abstraction and less depression storage. Consequently, it takes less rainfall to produce the same *volume* of runoff. Therefore, the *peak rate of runoff* that normally occurs on a 2-year frequency before development, may occur several times a year following development.

To compound the problem, a detention basin stores the increased *volume* of runoff from a developed area and releases it at the pre-developed rate. The *duration* of this discharge is much longer than the pre-developed condition. The peak rate and velocity may be at pre-developed levels, but by receiving the pre-developed rate for a longer *duration*, coupled with the increase in *frequency*, a stable earth-lined channel can quickly degrade.

The increased frequency of a specific discharge can be illustrated by considering an undeveloped watershed which, during a 2-year frequency storm (3.2 inches of rain), generates a theoretical peak rate of runoff of 15 cfs, and a corresponding volume of runoff of 0.52 watershed inches. We will assume that this 2-year frequency flow represents the channel forming, bankfull discharge. After the watershed has experienced development (32% imperviousness) along with the associated improved drainage conveyance systems, the same watershed requires only 1.6 inches of rainfall to generate that same theoretical bankfull discharge of 15 cfs. This means that the channel will now experience bankfull flows at an approximate increased *frequency* of every three to six months rather than two years. In addition, for the 2-year storm, the *volume* of runoff has increased to 1.15 watershed inches, more than double the pre-developed volume, which means a significant increase in the *duration* of the peak flow can be expected. Under this scenario, the receiving stream will experience a significant increase in erosive flows.

The solution to designing for stream channel erosion is evolving into a study of stream channel geomorphology. Several studies have indicated that the level of erosion (or bed-material load) is a function of the difference between the flow velocity and the *critical* velocity.(McCuen, 1987). The critical velocity is a function of the type of soil of which the channel bed is composed. The studies indicate that the amount of bed sediment moved is a function of the time duration over which the velocity is greater than the critical velocity. According to McCuen, this explains from a conceptual standpoint why the duration of flow is just as important as the rate of flow. Further, it may explain why detention basins may actually increase the erosion compared to providing no control of the post-developed flows. When no control is provided, the flow tends to exceed the channel capacity and extend out into the floodplain; thus the velocity within the channel banks may not increase significantly even though the peak flow rate does increase significantly.

This should not be interpreted as justification for no control of stormwater runoff. Rather, it highlights the need for a design criteria that replicates the pre-development sediment load transport characteristics of the channel. Several methodologies have been recommended, some of which are very subjective as they are based upon the ability of the designer to analyze and interpret the stream sediment characteristics. This could easily become an expensive and cumbersome methodology, especially in localities that do not experience significant development pressure. The review and approval process could become bogged down in the analysis of field data and trying to verify the channel characteristics, especially when the requirements of the field work may be different for every project.

The Virginia Stormwater Management Regulations address stream channel erosion by requiring compliance with Minimum Standard 19 of the Virginia Erosion and Sediment Control Regulations (4VAC50-30-40.19). This standard requires that **properties downstream from development sites be protected from sediment deposition, erosion, damage due to increases in volume, velocity, and peak flow rate of stormwater runoff**. The specific design criteria specifies that downstream *natural channels* by analyzed for adequacy to convey the developed condition 2-year peak discharge within the channel banks and at a non-erosive velocity. In addition, *man made channels* are analyzed for adequacy to convey the 10-year peak discharge within the channel banks and the 2-year peak discharge at a non-erosive velocity.

When a channel is determined to be not adequate, the use of a stormwater detention BMP sized to discharge the 2-year and 10-year frequency developed-condition peak discharge at the respective pre-developed rates is one of the available options. (Refer to **Chapter 1** for the complete language of Minimum Standard 19.) As we discussed above, this criteria may not be adequate for natural channels due to the increase in the frequency, duration, and volume of the "pre-developed" discharge.

An alternative is to identify a design frequency storm and control the discharge such that it does not exceed that of the critical velocity for the channel. Recent studies have shown a significant reduction in stream channel erosion below facilities designed to provide 24-hour extended-detention of the runoff from the 1-year frequency storm. (Galli MWCOG, 1992). This criteria results in significantly lowered discharge rates and velocities considered to be non-erosive, despite the longer impact time and increased frequency. The Virginia SWM Regulations allow this criteria as an alternative to the 2-year peak discharge control requirement in cases where natural channels are experiencing erosion resulting from existing conditions, or where channels are considered to be sensitive to any increase in flow rate or duration.

Further guidance on the analysis of the adequacy of natural channels, consistent with the Erosion and Sediment Control Regulations will be provided by the DCR in the near future.

2-2.3 Flooding

Control of the 10-year frequency design storm to the pre-developed rate is considered to provide control over a wide range of storms for control of localized or out of bank flooding. This should not be confused with out of bank flooding as it pertains to the 100-year floodplain which is mapped by the Federal Emergency Management Agency (FEMA), and based on the 100-year frequency design storm. The mapped 100-year floodplain is important because it is used to designate and implement the National Flood Insurance Program. Most localities in Virginia have a Floodplain Management Ordinance which controls development within the 100-year floodplain.

2-2.4 More Stringent Criteria

Local programs are authorized under the Virginia Stormwater Management Act to require more stringent technical criteria than the state minimum criteria found in the regulations (4VAC3-20). The more stringent criteria must be based on a watershed plan or study which justifies the criteria, and must be passed into local ordinance through the local ordinance adoption process. The scope of an acceptable watershed plan or study is somewhat subjective and, at a minimum, must stand up to the scrutiny of the local adoption process. Some basic watershed plan concepts are provided in **Section 2-4**.

2-3 BMP SELECTION CRITERIA

The following discussion provides a general outline for choosing the appropriate BMPS for a development site. The order of presentation **does not** imply a decision making process that will systematically progress towards an acceptable BMP. On the contrary, any one of the criteria can render a preferred BMP unacceptable. **In some cases**, the designer may be able to accommodate certain limiting feasibility factors by providing an innovative design which addresses or remedies the constraint. **In all cases**, once a BMP is selected, we strongly recommend that the selection, along with the supporting criteria and any compromises or design features, be presented to the various review or permitting agencies to ensure proper evaluation and review. This will help avoid extensive changes to the stormwater management strategy during the review process.

One of the first considerations in selecting a stormwater BMP is the functional goal of the BMP. Previously, we discussed the components of SWM: *stormwater quality*, *stream channel erosion*, and *flooding*. Any one or combination of these components may be addressed by the local ordinance and will dictate the functional goal of the BMPs. (State agency projects, are required to comply with all three of these regulatory components). In general, stormwater BMPs can be categorized into water *quality* BMPs and water *quantity* (stream channel erosion and flooding) BMPs. **Table 2-2** provides a general categorization of BMPs by functional goal. Note, that some BMPS can be designed to satisfy both quality and quantity goals while others are specifically suited for only one.

The use of some BMPS are limited by site or watershed feasibility factors such as environmental impacts, drainage area or watershed size, and topographic constraints.

Finally, the BMPS designed for water quality control provide varying levels of pollutant removal and are suited for specific development densities. **Table 2-3** presents a generic list of water quality BMPS, their target phosphorus removal efficiency, and appropriate percent impervious cover.

The decision making process of choosing a stormwater BMP must weigh the goals of the proposed facility against the limiting site feasibility factors of the proposed site or BMP location. The limiting *site feasibility* factors include:

1. Topographic and geologic constraints,
2. Contributing drainage area size, and
3. Environmental impacts.
4. Access for maintenance

The possible stormwater management requirements or goals which influence BMP selection include:

1. Multiple Criterion: Stormwater quality, stream channel erosion, flooding, and environmental mitigation,
2. Multiple discharge points,

3. Pollutant removal capability, and
4. Performance-based vs technology-based water quality criteria.

2-3.1 Site Feasibility

1. Topographic and Geologic Constraints

The physical characteristics of the site must be compatible with the performance of the BMP. Reviewing the **Minimum Standards** found in **Chapter 3**, you will note that BMPs are restricted in certain areas based on the geologic or underlying conditions. This can be as simple as determining if the hydrologic soil group is appropriate for the BMP (such as infiltration in permeable soils) or may require a vigorous geotechnical investigation.

a. *Karst topography:* Karst topography consists of geologic formation underlain by carbonate rock and typified by the presence of limestone caverns and sink holes. These areas present very difficult challenges since any BMP which impounds water may cause underlying caverns or sink holes to expand and open at the surface. The use of liners may help the BMP hold the runoff as intended, however, the conveyance to the BMP, as well as the conveyance from the BMP to the receiving channel must also be considered since the overall volume of runoff is increasing and possibly being directed to areas previously not impacted by runoff.

   In addition, the presence of karst may allow a direct path for the stormwater runoff to enter the water table with little or no filtering of pollutants. Any design in regions suspected to include karst topography should be supported by a thorough subsurface geotechnical or geological investigation. Further guidance on geotechnical methods for karst topography will be provided by the Department in the near future.

b. *High water table*: A high water table can impact the proper functioning of a BMP. Infiltration BMPs are restricted since a high water table will prevent the percolation of the stormwater into the sub soils. A high water table may cause dry detention BMPs to evolve into wet facilities. While this may enhance pollutant removal by encouraging a marsh environment, it may not be the choice of design based on maintenance, aesthetics, etc. A high water table may also impact the construction of the embankment or impoundment facilities by making it difficult to achieve the proper compaction of the underlying foundation. Special geotechnical recommendations may be necessary to address impacts associated with a high water table.

c. *Bedrock:* The presence of bedrock close to the surface can have a significant impact on a development project. The cost of excavation increases considerably, especially if blasting is required. Blasting rock in the area of a proposed embankment is not acceptable unless a liner system is proposed for the basin. Blasting can open seams in the bedrock which may allow stormwater to drain out of (or under) the proposed facility.

A thorough geotechnical investigation and report should verify the subsurface conditions for the presence of any of the above features. The scope and requirements of a geotechnical investigation may vary from site to site. Refer to **Minimum Standard 3.10: General Infiltration Practices** for additional information on geotechnical investigations.

d. *Proximity to structures, steep slopes, and water supply wells.* One of the goals of stormwater facilities is to provide recharge of the groundwater. This tends to saturate the adjacent ground during, and for a period of time, after, a storm event. Building foundations, basements, and other structures may be impacted by the wet/dry cycle of the surrounding soils.

Saturating the soils on or adjacent to steep slopes (6 to 10 percent or greater) can cause a failure of the slope and adjacent structures.

The proximity to water supply wells raises concern over the introduction of pollutants into the water supply aquifer. Minimum distances from these features are presented in **Chapter 3: Minimum Standards**.

2. Contributing Drainage Area Size

Some BMPs are restricted based upon the size of the contributing drainage area. The recommended maximum and minimum sizes are considered guidelines and some flexibility should be allowed. The exceptions, however, are the Manufactured BMP Systems (**Minimum Standard 3.15**) The manufacturers design criteria should be adjusted or modified **by the manufacturer only**. The proper operation of these BMPs is dependent on the proper sizing of the structure.

3. Environmental Impacts

It is extremely important for the designer to asses the environmental impacts associated with the site development and the placement of the stormwater BMP. Local, State, and Federal regulations may restrict the disturbance, or encroachment upon any of the following: wetlands, Waters of the United States, stream or wetland buffers, floodplains, conservation easements, and other sensitive resources.

Virginia Water Protection Permit Program: The Virginia Department of Environmental Quality implements the Virginia Water Protection Permit (VWPP) Program. This program regulates all activities in Virginia which result in discharge or dredge or fill material into state waters. This can include wetlands, perennial streams, and other aquatic resources. The VWPP program is in conjunction with the U.S. Corps. of Engineers Federal Permit authorized by the Clear Water Act. Some projects may require one or both permits. The permit typically requires that the developer investigate alternatives to the proposed impacts. If no alternatives are viable, then possible design modifications may be needed, such as pre-treatment of stormwater prior to discharging into wetlands, thermal and dissolved oxygen impacts to the receiving stream be addressed, etc. The designer should contact the appropriate state or federal agencies prior to the design to identify such permit requirements.

Chesapeake Bay Preservation Act: The Chesapeake Bay Preservation Act (CBPA) and regulations, implemented by local governments, contain restrictions on development within certain buffer areas of wetlands, streams and other sensitive water resources. The designer should contact the Chesapeake Bay Local Assistance Department or the local government prior to the design to identify the restricted buffer areas and other requirements of the CBPA and regulations.

National Flood Insurance Program: The Department of Conservation and Recreation (DCR) coordinates the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP) in Virginia. Local governments implement local floodplain management ordinances consistent with the state and federal statutes. The designer should contact DCR or the local government prior to design in order to identify any mapped 100-year foodplain located on the project.

2-3.2 Site or Watershed Stormwater Management Requirements

1. Multiple Criterion: Quality, Stream Channel Erosion, and Flooding

The functional goal of the stormwater BMP will be determined by the regulatory requirements imposed on the site. In some cases the downstream receiving waters will influence the regulatory requirements. Where multiple controls are required (quality and quantity), ideally these controls can be satisfied in one BMP strategically located on the site. This is usually accomplished with an impoundment BMP such as *extended detention* or *retention*.

On small sites, however, the use of impoundment facilities is limited by the available space, and their inability to adequately serve small areas for water quality. (The small orifice diameter required for adequate extended detention time can easily become a maintenance burden for a small site, and the contributing drainage area size should be at least 25 acres or contain a base flow when considering a retention basin.) Therefore, it may become necessary to utilize more than one BMP: one which addresses quantity and another which addresses quality. Reducing the stormwater quantity requirements through non-structural BMPs or innovating site design techniques will help to reduce the need for structural quantity control BMPs which typically are land intensive.

2. Multiple Discharge Points

The simplest site design includes a stormwater management strategy that consists of one discharge point from the site. Large developments, however, often contain multiple discharge locations as dictated by the topography. Traditionally, this situation has been addressed one of two ways: 1) Provide a Stormwater BMP at each location as required by the size of the contributing drainage area and associated increase in peak discharge, percent imperviousness, etc; or 2) overcompensate at one discharge point in order to allow the other discharge point(s) to go uncontrolled.

Overcompensation of Peak Discharge should be subject to the following conditions:

1. The drainage channels which leave the site must be part of the same stream or tributary network and the confluence should occur at some reasonable distance from the site.

2. The uncontrolled discharge is still subject to the requirements of MS-19, that is the receiving channel is adequate to convey the increased flow.

3. The overall peak rate of discharge leaving the site must not exceed that of the pre-developed condition.

Overcompensation of Water Quality is covered in more detail in the next section which discusses the use of the Performance-based Water Quality Criteria. However, as it applies to multiple discharge points, the following conditions should apply:

1. The drainage channels which leave the site must be part of the same stream or tributary network and the confluence should occur at some reasonable distance from the site.

2. Every effort should be made to provide water quality enhancement through the use of vegetated buffers, open grass/vegetated swales, bioretention, or other low maintenance water quality BMPs.

3. Every effort should be made to minimize the impacts in the uncontrolled drainage area through non-structural means as discussed previously.

4. The overall site water quality compliance must be determined using the performance-based water quality criteria.

Another alternative which may be considered is the control of existing development in lieu of the proposed development. This trade off should be considered only if specific site, watershed, or environmental considerations hinder the successful incorporation of on-site BMPs.

3. Pollutant Removal Efficiency

Years of pollutant removal monitoring of stormwater BMPs has provided us with a basic understanding of how efficient various BMPs are at removing urban pollutants. Most of this knowledge is limited to the older and more traditional impoundment BMP structures such as *retention* and *extended detention*. Recent regulatory requirements focused on reducing the export of nonpoint source pollution have given rise to new BMPs, some of which have had very limited monitoring with which to verify removal efficiencies. The pollutant removal efficiencies provided in the stormwater regulations and this handbook are derived from the best available information. We recognize that these values are subject to change as we learn more about the practical application and maintenance of these new BMPs.

Keystone Pollutant

The pollutant removal efficiencies presented in **Table 2-4** are removal efficiencies for phosphorus. This target or keystone pollutant was selected by the Chesapeake Bay Local Assistance Department in order to evaluate the performance of site design and BMPs at reducing pollutant export from a development site. The selection of one pollutant allows a consistent application of a performance based water quality criteria. Phosphorous was selected because it exhibits some of the characteristics of particulate pollutants, as well as those of soluble pollutants, making it a good indicator of urban pollutants in general. This is not meant to exclude other pollutants from being targeted. The performance-based water quality calculation procedure was originally adopted as guidance in the Chesapeake Bay Local Assistance Department's *Local Assistance Manual* for localities implementing Chesapeake Bay Preservation Act (CBPA) programs. In situations where other pollutants are identified as a problem, such as from "stormwater hotspots", those other pollutants should be addressed.

Stormwater Hotspots

Stormwater hotspots are defined as a land use or activity that generates higher concentrations of a particular pollutant or pollutants, such as sediment, hydro-carbons, trace metals, or toxicants, than are found in typical stormwater runoff, based on monitoring studies. (Center for Watershed Protection, 1997). The use of some BMPs are limited on sites considered to be stormwater hotspots. This is due to the potential for the contamination of groundwater. *Infiltration facilities* are not recomended for hotspots for this reason. Further, the use of impoundment type structures for hotspots should be qualified by an adequate separation from the seasonal groundwater table (four foot separation is desirable, and a two foot separation minimum), or an impermeable liner used to prevent leachate infiltration

TABLE 2-2
Functional Goal of Stormwater BMPs

Stormwater BMP	Quality	Stream Channel Erosion	Flooding
Vegetated filter strip	U++		
Grassed Swale (w/ check dams)	U++	U	
Constructed wetlands	U++	U	
Extended detention	U+	U++	U
Extended detention enhanced	U++	U+	U
Bioretention	U++		
Retention basin	U++	U+	U
Sand filter	U++		
Infiltration	U++		
Infiltration Basin	U+	U	U
Detention		U+	U++
Manufactured BMPs	U++		

Legend: U++ = Primary functional goal

U+ = Potential secondary functional goal

U = Potential secondary functional goal with design modifications or additional storage

NOTE: *Some BMPs, when properly designed, can provide secondary goals. Table 2-2 indicates several water quality BMPs with potential secondary goals. This is not meant to restrict the designer from incorporating design modifications or additional storage as appropriate for the particular site. Care must be taken to ensure that the the design modifications do not diminish the primary goal capabilities of the BMP.*

TABLE 2-3
Target Phosphorus Removal Efficiency*

Water Quality BMP	Target Phosphorus Removal Efficiency	Percent Impervious Cover
Vegetated filter strip Grassed swale	10% 15%	16-21%
Constructed wetlands Extended detention (2 x WQ Vol) Retention basin I (3 x WQ Vol)	30% 35% 40%	22 -37%
Bioretention basin Bioretention filter Extended detention-enhanced Retention basin II (4 x WQ Vol) Infiltration (1 x WQ Vol)	50% 50% 50% 50% 50%	38 -66%
Sand filter Infiltration (2 x WQ Vol) Retention basin III (4 x WQ Vol with aquatic bench)	65% 65% 65%	67 -100%

** Innovative or alternate BMPs not included in this table may be allowed at the discretion of the local program administrator or the Department. Innovative or alternate BMPs not included in this table which target appropriate nonpoint source pollution other than phosphorous may be allowed at the discretion of the local program administrator or the Department.*

TABLE 2-4
Classification of Stormwater Hotspots

The following land uses and activities are deemed *stormwater hotspots*

< vehicle salvage yards and recycling facilities #
< vehicle fueling stations
< vehicle service and maintenance facilities
< vehicle and equipment cleaning facilities #
< fleet storage areas (bus, truck, etc.) #
< industrial sites (for SIC codes contact Virginia Dept. Of Environmental Quality)
< marinas (service and maintenance) #
< outdoor liquid container storage
< outdoor loading/unloading facilities
< public works storage areas
< facilities that generate or store hazardous materials #
< commercial container nursery

# indicates that the land use or activity is required to prepare a stormwater pollution prevention plan in accordance with the Virginia Pollution Discharge Elimination System program permit as required by the Virginia Department of Environmental Quality.

Source: Center for Watershed Protection, 1997

2-3.3 *Technology-Based* and *Performance-Based* Water Quality Criteria

The *Technology-based* and *Performance-based* water quality criterion represent a consolidation of the water quality technical criteria of three state agencies charged with the responsibility of monitoring and improving the water resources of the Commonwealth: The Department of Conservation and Recreation (DCR), the Department of Environmental Quality (DEQ), and the Chesapeake Bay Local Assistance Department (CBLAD). The specific responsibilities of these agencies are presented in **Chapter 1**. The stormwater management water quality regulations require compliance by **either** a *performance-based water quality criteria* **or** a *technology-based water quality criteria*.

The *performance-based* water quality criteria states that for land development, the calculated post-development nonpoint source pollutant runoff load shall be compared to the calculated pre-development load based upon the average land cover condition or the existing site condition. This approach requires the designer to calculate the pollutant load to be removed, implement a BMP strategy, and then calculate the performance of that strategy, based on the effectiveness or pollutant removal efficiency of the selected BMP(s), (**Table 2-3**) .

The calculation procedure for verifying compliance with the performance-based water quality criteria is based on the Simple Method. The *Simple Method* is empirical in nature and utilizes the extensive data base obtained in the Washington D. C. National Urban Runoff Pollution (N.U.R.P.) study, as well as the national N.U.R.P. data analysis (MWCOG, 1983) to establish pollutant loading values for various land uses. The derivation of the Simple Method can be found in Appendix A of Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs, published by The Metropolitan Washington Council of Governments.

The *technology-based* water quality criteria states that for land development, the post-developed stormwater runoff from the impervious cover shall be treated by an appropriate BMP as required by the post-developed condition percent impervious cover as specified in **Table 2-3**. The selected BMP shall be located, designed, and maintained to perform at the target pollutant removal efficiency specified in **Table 2-3**.

These two criterion are considered to be equivalent when implemented as described in this handbook. The design criteria found in **Chapter 3** establishes the minimum design elements which should result in the expected pollutant removal performance of the BMP.

1. Performance-Based Water Quality Criteria

The *performance-based water quality criteria* states that for land development, the calculated post-development nonpoint source pollutant runoff load shall be compared to the calculated pre-development load based upon the average land cover condition or the existing site condition. A BMP shall be located, designed, and maintained to achieve the target pollutant removal efficiencies specified in **Table 2-3** to effectively reduce the pollutant load to the required level based upon the following four applicable land development situations for which the performance criteria apply:

1. *Situation 1* consists of land development where the existing percent impervious cover is less than or equal to the average land cover condition and the proposed improvements will create a total percent impervious cover which is less than the average land cover condition.

   Requirement: No reduction in the after development pollutant discharge is required.

2. *Situation 2* consists of land development where the existing percent impervious cover is less than or equal to the average land cover condition and the proposed improvements will create a total percent impervious cover which is greater than the average land cover condition.

   Requirement: The pollutant discharge after development shall not exceed the existing pollutant discharge based on the average land cover condition.

3. *Situation 3* consists of land development where the existing percent impervious cover is greater than the average land cover condition.

> Requirement: The pollutant discharge after development shall not exceed (i) the pollutant discharge based on existing conditions less 10% or (ii) the pollutant discharge based on the average land cover condition, whichever is greater.

("...which ever is greater" refers to the calculated pollutant discharge to which the after development pollutant discharge is compared. Additional explanation is provided in the discussion following this section.)

4. *Situation 4* consists of land development where the existing percent impervious cover is served by an existing stormwater management BMP that addresses water quality.

> Requirement: The pollutant discharge after development shall not exceed the existing pollutant discharge based on the existing percent impervious cover while served by the existing BMP. The existing BMP shall be shown to have been designed and constructed in accordance with proper design standards and specifications, and to be in proper functioning condition.

The definition of the average land cover condition is important to the successful implementation of the performance-based water quality criteria. An analysis of the Chesapeake Bay watershed identified the average land cover condition using the following categories: urban land use, forest cover, pasture land, conservation till acreage, and conventional till acreage. Using the pollutant load values from the N.U.R.P. studies, the average land cover condition was then used to establish a baseline existing land use condition pollutant load value of 0.45 lb/ac/yr of phosphorous. Since the Simple Method is based on impervious cover, an equivalent percent impervious cover is needed. 16% impervious cover has been determined to be an equivalent pollutant load source for all of the urban and non-urban land uses which contribute nonpoint source pollution. These values (16% impervious cover and 0.45 lb/ac/yr of phosphorous) represent the average land cover conditions for the Chesapeake Bay watershed. (Keep in mind that these values may be adjusted based on actual land use conditions within the locality or individual watersheds within the locality at the time of DCR or CBLAD program adoption, whichever occurred first.) This allows the designer to calculate, using the Simple Method, the pre-developed pollutant load using average land cover conditions, and the post-developed pollutant load using the project post-developed impervious cover. The difference between the pre- and post-developed pollutant load represents the increase in pollutant load which must then be controlled by an appropriate BMP.

Since this methodology is based on impervious cover, there may be some developments such as golf courses, cemetaries, etc. which would be calculated as having no increase in pollutant load. Depending on the pre-developed land cover, this may or may not be the case. Unmanaged meadow which is graded into a golf course fairway will probably experience an increase in pollutant discharge. Since this is not accounted for in the calculation procedure, the designer and reviewer are encouraged to use sound engineering judgement in applying the water quality criteria. Site feasibility factors should be evaluated and an appropriate BMP selected in situations where the calculation procedures do not accurately reflect the post developed condition impact on water quality.

The designation of an average land cover condition helps to prevent extreme compliance situations. Without such a provision, a site in its natural state with very little runoff and NPS pollution, e.g. a forested site, might become impossible to develop simply because currently available BMPs may not be able to satisfy the pollutant removal requirement of *post* back to *pre*. Conversely, a development of open land with sparse vegetation may generate a significant pre-development load such that careful development of the site, without the use of BMPs, may satisfy the rpollutant removal standard. The concept of average land cover condition attempts to provide a balance in implementing the performance-based and technology-based water quality criteria regulations.

The following presents a brief discussion of the four development situations and the application of the performance based criteria:

Development Situation 1 describes new low density development with a percent imperious cover of less than the average land cover condition (16% Chesapeake Bay watershed default value or a watershed specific value pre-determined by the locality).

Note that the designation of the 16% impervious cover value is not intended to be a threshold for water quality compliance. Simply stated, a development with less than 16% impervious cover should be reviewed for the type and distribution of the impervious cover prior to determining that no water quality measures are required.

A low density development with scattered disconnected impervious cover (such as lots sized at 1 acre or more) can easily be considered to have negligible impacts on water quality if the clearing and grading is limited to the minimum needed to build the road and site the houses (other considerations such as maintaining the natural stream buffers, avoiding steep slopes, and minimizing wetland impacts and tree removal should also be evaluated).

Some low impact development (LID) strategies recommend the clustering of development and the associated impervious cover and preserving open space. This strategy allows the overall impervious cover to be kept low while allowing for the preservation of high priority open space such as stream buffers and unmanaged open space. However, the clustered development represents a significant source of increased runoff and pollutant load when directly connected to the drainage system. Guidance on mitigating these impacts within the LID strategy can be found in the references provided at the end of this chapter.

If, on the other hand, the development consists of commercial or industrial development and associated infrastructure (parking lots, roads, and other impervious surfaces), located on a sufficiently large parcel such that the total area of impervious cover is less than 16%, and the improvements include a directly connected drainage network, then water quality controls should be provided. This type of development poses a very difficult development situation to regulate using the performance-based water quality criteria since the overall percent impervious cover is low. Initial efforts to define the impervious cover as connected or disconnected led to very awkward and subjective regulatory language. Another option considered revising the definition of *percent impervious* to read "the impervious area divided by the drainage area within the site multiplied by 100." Again, various development situations were presented which led to subjective interpretations of these definitions. The preferred method of dealing with this issue was determined to be clear guidance on the intent of the 16% impervious cover "average land cover condition," and a case by case evaluation of the application of the performance-based water quality criteria.

When improvements on a site are concentrated such that the impervious area is collected and drained to a single receiving channel (connected impervious cover), it is reasonable to expect that the developed condition runoff will have an impact on the receiving system in terms of water quality impairments, regardless of the overall "site" percent imperviousness, and therefore should be considered in the water quality strategy. In such cases, DCR recommends that the percent impervious cover calculation be based on the drainage area being collected by the improved drainage system.

Development Situation 2 describes new development which results in impervious cover greater than the average land cover condition. The selection and location of a BMP to satisfy the pollutant removal requirement is verified using the Simple Method.

Development Situation 3 describes development of a site with existing development already present. This development situation is provided to help create an incentive for development, or "redevelopment" of existing infrastructure as opposed to developing a raw piece of land. Clearly redevelopment contains more challenges with regard to existing utilities, building locations, entrances, drainage systems, etc. The requirement of 10% reduction in calculated pollutant load from the site allows flexibility in siting a BMP at the most advantageous location with regard to existing site restrictions. If the amount of impervious surface does not change significantly, the designer has the choice of several BMPs to achieve the 10% reduction including the Manufactured BMP Systems (**Minimum Standard 3.15**) which can be easily located on an existing storm system.

Development situation 4 accounts for redevelopment where the existing development is served by an existing water quality BMP. This implies that the BMP was specifically designed to serve as a water quality BMP. In order for the existing BMP to satisfy the criteria it must be shown to have been designed and constructed properly and be in good working condition. New maintenance agreements may be necessary for continued operation of the BMP, as well as design enhancements, to ensure continued successful operation in the new development or redevelopment condition.

The performance-based water quality criteria allows the designer to locate the BMP at the most advantageous location on the site relative to the post-developed drainage divides, topography, etc, in order to meet the "pollutant removal" requirements of the four development situations. The pollutant removal requirements are based on the anticipated pollutant load from the site. Since a "site" may consist of several distinct drainage areas and discharge points, the designer must apply the removal efficiency of the BMP to the area draining to the BMP only. If this does not meet the removal requirement for the site, additional BMPs must be located in other drainage areas until the total pollutant removal satisfies the requirements, or a more efficient BMP should be selected. (All drainage discharges **are** subject to Erosion and Sediment Control Minimum Standard MS-19 - Channel Adequacy).

BMPs with the same pollutant removal mechanisms should not be located in series (runoff flowing from one BMP to the next) with removal efficiencies simply summed together. Consideration should be given to the form of pollutant which is targeted for removal. Sources cite that approximately 40% of phosphorus is bound to sediment or in particulate form. Thus BMPs added in series which serve to remove only particulates (settling) will not significantly increase the pollutant removal efficiency. While there may be some additional removal efficiency, the increase is certainly less than the algebraic sum of the two individual efficiencies.

The performance-based water quality criteria and calculation procedures should generally be applied to subdivision developments on a whole, and not to individual lots. This is not a contradiction to the previous discussion, however, there does appear to be a certain amount of judgement required to effectively comply with the intent of the water quality criteria. Many subdivision type developments can be effectively controlled with several BMPs serving individual lots or concentrated areas of impervious cover. The calculation procedure accounting for several BMPs may still be applied to the whole parcel or development in order to calculate the total pollutant removal achieved by the BMP strategy (the BMP strategy in this case includes multiple BMPs).

2. Technology-Based Water Quality Criteria

The selection of a BMP using the technology-based water quality criteria is based on the imperviousness and size of the drainage area. Review of **Table 2-3** reveals that each BMP is associated with a range of impervious cover. The development of a highly impervious land use such as an office park, in the range of 38 - 66% impervious cover, would indicate that an appropriate selection of BMP should be bio-retention basin or filter, extended detention-enhanced, retention basin II, or infiltration (or any of the BMPs listed for an imperviousness range of 67 - 100%).

Likewise the development of a low density subdivision in the range of 16 -21% imperviousness would indicate the selection of a vegetated filter strip or grassed swale (or any of the more efficient BMPs). The designer need only verify using the performance-based calculation procedure that the required removal efficiency would dictate a similar selection, thus indicating the equality of the two methodologies.

The difference in the two methodologies is the ability to incorporate a combination of BMPs using the performance-based criteria. Consider the just mentioned office park. If an extended detention-enhanced basin is selected, yet does not capture the runoff from the entire site to the effect that the calculated pollutant removal of the BMP does not satisfy the site or planning area pollutant removal requirement, then an additional BMP or a more efficient BMP must be designed.

Consider, as part of the office park, a two acre parking area along the edge of the office park which does not drain to the extended detention-enhanced facility. The designer may choose to incorporate a grassed swale with check dams to control the two acre drainage area. Since the two acre drainage area is almost entirely impervious, strict application of the technology-based criteria would preclude the use of anything but the most efficient BMPs (sand filter, infiltration, etc.) The performance-based criteria, on the other hand, allows for a total pollutant removal to be calculated to measure the combined effectiveness of the more efficient extended detention-enhanced facility on the majority of the site along with the lower efficiency grassed swale serving the small portion of the site.

The use of sound judgement in the application of multiple BMPs should dictate. If the designer is using the technology approach to control a majority of the site, and proposes a less efficient BMP to control the small area draining in the other direction, the requirement to calculate the total site pollutant removal using the performance-based calculation procedure is at the discretion of the plan approving authority. On the other hand, if a portion of the development site is being left uncontrolled, the plan approving authority may certainly require the performance-based calculation procedure to verify compliance.

Several examples will be provided by DCR as guidance in these types of review decisions.

2-4 REGIONAL STORMWATER MANAGEMENT PLANS

The development of a regional stormwater management plan allows a local government to strategically locate stormwater facilities to provide the most efficient control of localized flooding, stream channel erosion, and water quality. In addition, a regional plan provides the added benefit of mitigating the impacts of existing development to allow for restoration of urbanized stream systems.

The objective of a regional stormwater management plan is to address the stormwater management concerns in a given watershed with greater economy and efficiency by installing regional stormwater management facilities versus individual, site-specific facilities. The result will be fewer stormwater management facilities to design, build and maintain in the affected watershed. It is also anticipated that regional stormwater management facilities will not only help mitigate the impacts of new development, buy may also provide for the remediation of erosion, flooding or water quality problems caused by existing development within the given watershed.

If developed, a regional plan shall, at a minimum, address the following:

1. The specific stormwater management issues within the targeted watershed.

2. The technical criteria in 4VAC3-20-50 through 4 VAC 3-20-85 as needed based on number 1 above.

3. The implications of any local comprehensive plans, zoning requirements and other planning documents.

4. Opportunities for financing a watershed plan through cost sharing with neighboring agencies or localities, implementation of regional stormwater utility fees, etc.

5. Maintenance of the selected stormwater management facilities.

6. Future expansion of the selected stormwater management facilities in the event that development exceeds the anticipated level.

The benefits of regional stormwater management plans are well documented by those localities which have implemented them. Likewise, adverse impacts are also documented. The debate over the merits of regional facilities versus the impacts is different in each watershed. The following provides a list of some of the more common issues frequently surrounding the decision making process. Future guidance, in conjunction with the Corps of Engineers and the Department of Environmental Quality, will be provided by DCR.

Asserted problems with on-site facilities:

1. Not as efficient at pollutant removal as larger facilities.

2. More land is disturbed because of need for a number of smaller facilities; an additional 5 to 10 acres will not be available for development out of every 1, 000 acres served by stormwater management facilities.

3. Not well maintained, reducing pollutant removal efficiency.

4. More complicated for localities to maintain a large number of small facilities.

5. Access may be more difficult.

6. Do not typically have maintenance features such as forebays, access roads, and sediment disposal areas. Difficulty in access and maintenance often results in maintenance responsibility being shifted to homeowner's associations, which experience has shown, are not generally capable of coordinating the public works function required to effectively maintain stormwater management facilities. Uncertainty of maintenance puts long- term reliability of the facility in question.

7. Pose a greater public safety hazard.

8. Have more potential to become "eyesores."

9. Can only be sited to address stormwater discharges from future development since they are implemented for individual development projects only.

10. More expensive.

11. May result in a haphazard siting pattern for stormwater management facilities; with only limited control of down stream erosion and flooding.

Asserted benefits of regional facilities:

1. More efficient and ensure the highest possible efficiencies for the entire watershed, rather than one small site.

2. Offer the ability to control temperature of outflow which is not possible with small facilities.

3. Can be strategically located within a watershed and designed for coincident stormwater releases,

resulting in a coordinated system of controls.[1]

4. Can be located to control some existing, as well as future, development and can compensate for pre-existing development that does not have adequate (or any) stormwater control to help reduce stream bank erosion and negative impacts to downstream floodplains and wetlands.

5. More likely to be adequately maintained.

6. Lower lifetime maintenance cost; more easily accessed and maintained.

7. Provide a recreational amenity.

<u>Asserted adverse consequences that may result from regional facilities</u>:

1. Reaches of a stream above an instream facility receive untreated stormwater containing a variety of pollutants that adversely impact water quality and stream habitat.

2. Upstream inundation from the pond's impounded water destroys floodplains, wetlands and stream habitats.

3. Changes in water depth and frequency and duration of flooding can change the plant communities above and below the pond.

4. Wet ponds block the passage of fish and other aquatic life that normally move up and down the stream and disrupt the downstream movement of food particles, which are the base of the food chain for stream ecosystems.

5. The hydrologic change caused by the impoundment will eliminate species that thrive on flowing stream conditions, but cannot tolerate ponded conditions.

6. Water temperature increases in the pond, as well as downstream, due to incoming runoff can eliminate certain species of fish and aquatic insects.

7. Are more likely to be located in and adversely impact wetlands.

8. Large regional facilities are more difficult to administer because the locality must (1) prepare

[1] Peak flow reductions are only localized in nature because of several factors: The small drainage area controlled by each facility; the extended duration over which the facility releases stormwater flows; the relatively high peak release rates from the on-site facilities (compared to regional facilities which can be sized to achieve release rates that are much less than pre-development conditions); and interactions among releases from on-site facilities which are not coordinated.

a master plan specifying the sites and design criteria, (2) implement a phased construction program so that facilities are in place when new development occurs, and (3) recover pro-rata charges from new development or establish a stormwater utility with which to offset the costs for the regional facilities.

2-5 COMPREHENSIVE WATERSHED MANAGEMENT

The 1994 General Assembly passed Senate Joint Resolution (SJR) No. 44 which allowed for the continued study of the efficiency and consistency of the stormwater management and permitting policies of the Commonwealth. The resolution included, among other elements, the study of approaches to watershed management of stormwater. The following incorporates the findings of the Technical Task Force of the SJR 44 Joint Study Committee.

A comprehensive watershed management plan is the result of studying the environmental and land use features of a watershed to identify those areas that should be protected and preserved and stormwater management measures and design criteria to be utilized to protect such areas so that development, when it does occur, will not negatively impact water resources. In so doing, watershed planning uses and protects ecological processes to lessen the need for structural control methods that require capital costs and maintenance. By including consideration of the watershed and its characteristics, cumulative impacts and inter-jurisdictional issues are more effectively managed than when solely relying on a single site permit approach. Watershed planning can be an important tool for maintaining environmental integrity and economic development.

The Stormwater Management Act (§10.1 - 603.1 et. seq. of the Code of Virginia) enables localities to adopt more stringent stormwater management criteria than those promulgated in the Stormwater Management Regulations (4VAC3-20), provided that the more stringent regulations are based upon the findings of local comprehensive watershed management studies.

Historically, a watershed or regional plan simply focused on the implementation of regional stormwater management facilities within a designated watershed. As our understanding of the dynamic relationship between development and water resources grows, so should the goals of a watershed plan. A watershed plan should provide:

- guidance as to the areas and resources to avoid and protect,
- development guidelines to minimize the impacts of new development on water resources,
- identification of retrofit opportunities such as BMP retrofits, stream restoration, etc. to mitigate impacts resulting from existing development, and
- appropriate stormwater management options (structural and non-structural) including design criteria and locations.

To accomplish these goals, a watershed plan should consist of three components: **Inventory, Planning, and Implementation.**

These three components include the following:

A. Inventory

1. **Define the watershed boundary.**
2. **Conduct a watershed inventory of natural resource features** (wetlands, floodplains, stream corridors, greenways, rare and endangered species, steep slopes, erodible soils, karst bedrock areas, sensitive habitats, fish and wildlife resources, recreational areas, sources of water supply).
3. **Conduct a stream inventory** (size, order, water and habitat quality, flow regime).
4. **Identify significant environmental features in neighboring watersheds** (large pollution sources, wildlife refuges, sources of water supply).
5. **Identify and quantify existing sources of point and nonpoint source pollution.**
6. **Model the existing hydrology and hydraulics of the watershed** (understand the impact of land use, conveyances, land cover, stormwater management facilities, stream cross sections, roadway crossings, flooding and drainage problems).

B. Planning

1. **Define the goals of the watershed management plan** (what is envisioned for the watershed and who is going to lead the implementation efforts).
2. **Identify and quantify future sources of point and nonpoint source pollution.**
3. **Model the future hydrology and hydraulics of the watershed.**
4. **Develop and evaluate alternatives to meet the goals and manage water quality** (point and nonpoint source pollution) **and quantity** (hydrology and hydraulics).
5. **Identify opportunities to restore natural resources.**
6. **Develop the watershed management plan** (include specific recommendations on development and land use evaluation, selection of structural and non-structural BMPs, public education needs, regulatory requirements, and funding).

C. Implementation

1. **Identify the stakeholders responsible for developing, implementing and updating the plan to ensure long-term accountability.**
2. **Define the implementation costs** (capital costs and annual administrative, operations and maintenance costs) **and who will pay for the implementation of the watershed management plan** (provide incentives and secure commitments).
3. **Develop a watershed monitoring program.**
4. **Develop an evaluation and revision process for the watershed management plan.**
5. **Establish and implementation schedule.**

The process described in the following sections is based on the above mentioned steps and can be used to develop a watershed management plan for any watershed. The amount of effort expended on each step depends on the specific goals of the project, the data available, and the people involved in preparing and implementing the plan. Some of the steps need to be conducted concurrently to facilitate a successful implementation of the plan.

2-5.1 Inventory of Watershed Characteristics

The inventory of the watershed characteristics will serve as the basis for the design and location of BMPs at the regional (watershed) level and flood/erosion controls. The inventory data will be integrated with information from the planning and implementation components to develop the watershed management plan.

1. Define the Watershed Boundary

In order to develop a meaningful and implementable watershed management plan, an appropriate watershed or subwatershed needs to be selected. Watershed plans often end up on the shelf because the size of the watershed was too large (greater than 60 square miles) and the focus of the plans became too fuzzy (Center for Watershed Protection, 1996). In addition, the impacts of different land uses on the watershed hydrology, stream health and water quality is difficult to evaluate, unless very detailed models are developed.

Municipalities can be subdivided into watersheds or subwatersheds ranging from 2 to 20 square miles in drainage area. When these watershed or subwatersheds extend beyond the municipality's corporate limits, efforts should be made to develop memoranda of understanding with adjacent jurisdictions to facilitate and promote implementation of watershed management plans. Once the watershed or subwatersheds are delineated, the municipality can prioritize the development of watershed management plans based on local needs and water quality and quantity criteria.

2. Conduct a Watershed Inventory of Natural Resource Features

Successful implementation of a watershed management plan will also depend on the ability to obtain the appropriate permits from state and federal agencies. An inventory of natural resource features in the watershed will promote the development of a BMP siting approach that minimizes or avoids impacts on environmental resources to the maximum extent practicable. This BMP siting approach will facilitate permitting.

The natural resource features to be inventoried would depend on the characteristics of the watershed being studied and could include:

- Wetlands
- Floodplains
- Stream corridors and greenways
- Steep slopes
- Erodible soils
- Karst bedrock areas
- Rare and endangered species
- Sensitive habitats
- Cultural resources
- Fish and wildlife resources
- Recreational areas
- Sources of water supply

Wetlands

Wetlands provide unique habitats for both plants and wildlife, including many threatened and endangered species. As a consequence, wetlands are valued for aesthetic and recreational reasons. Wetlands also provide valuable flood storage, groundwater recharge, and pollutant-filtering functions.

Wetlands are widely scattered throughout Virginia and commonly are encountered on development sites and throughout watersheds. Protecting the natural functions of wetlands is a critical element of the site development process and watershed management planning. For moderate- to high-quality wetlands, which are very difficult to replace, avoidance is recommended. If the watershed contains scattered, small, low-quality wetlands, which are more readily replaced, mitigating the wetlands at a central location may be more appropriate, thereby enhancing wetland functions and reducing a potential constraint to development. Early coordination with resource agencies is recommended.

Floodplains and Stream Corridors

Floodplains and stream corridors include waterways and adjacent riparian lands that may be subject to flooding. Natural waterways provide habitat for fish, aquatic plants, and benthic (bottom dwelling) organisms. Development in waterways may destroy aquatic organisms and introduce large loads of sediment and pollutants into the waterways. Modifying waterways to accommodate development also may destroy the physical features essential to a good habitat, including: stable stream banks and bottom substrates, pools and riffles, meanders, and spawning areas.

Vegetated riparian land adjacent to streams stabilizes the stream bank, filters pollutants from storms and floods, and provides habitats for a variety of amphibians, aquatic birds, and mammals that depend on the proximity to water for their life functions. Development in floodplains and riparian corridors can impair the functions and subject structures to damage from flooding and the meandering of natural streams.

A filter strip or riparian-forested buffer should be preserved or created along the banks of streams, where possible. Furthermore, consideration should be given to establishing setbacks for intensive development (e.g., buildings, parking lots, roadways). This will minimize the potential for sediment releases to the streams, as well as maintain the corridor to achieve flood control, water quality, and habitat enhancement objectives. If a development site contains a highly channelized stream, the best interest of both the developer and the aquatic resource may be served by restoring the stream corridor.

Shorelines of ponds, lakes, and wetlands provide many of the same functions as riparian stream corridors provide for streams. Stable vegetated shorelines are particularly valuable in preventing erosion caused by wave action. Protection of shorelines should be considered when developing water dependent development, such as piers and marinas (CH2M HILL, 1998).

Steep Slopes and Highly Erodible Soils

From an erodibility standpoint, the definition of steep can vary depending on surface soil type and underlying geology. In general, extra caution is warranted on a slope exceeding 10 percent (1 foot of vertical drop per 10 feet of horizontal distance). However, even flatter slopes that have soil classified as highly erodible should be identified as steep.

Disturbing steep slopes with development causes instability of the soil on the slopes. Inappropriate development destroys vegetation, root systems, and soil structures. High runoff velocities from exposed steep slopes result in destructive and unsightly erosion, denuded slopes that may be difficult to revegetate, and sediment deposition in sensitive areas both on and off the site.

A general rule to be followed in site development is to minimize the area and time of disturbance and to fit the development to the natural terrain. Stabilizing vegetation should be protected to the maximum extent practicable and disturbed areas should be immediately revegetated. Extending this general rule to the entire watershed will promote preservation of natural resource features.

Karst Bedrock Areas

Karst bedrock areas are underlain by bedrock containing soluble minerals. Karst areas develop voids and solution channels as groundwater gradually dissolves the bedrock. In these terrains groundwater flow can be extremely rapid and unpredictable. Furthermore, the concentration of runoff may stimulate the formation of sinkholes. Sinkholes can develop as flowing water exposes and then washes into the mouths of the near surface openings of subterrain channels and caverns. Rapid degradation of groundwater resources can result when sediment or pollutant laden runoff percolates into karst bedrock aquifers.

Several areas of Virginia are underlain by limestone, dolomite, or marl carbonate rocks which are potentially susceptible to the development of karst conditions. Before introducing site alterations that could concentrate or pond runoff, the presence or absence of carbonate bedrock should be established. If carbonate rocks do occur a professional geologist or civil engineer should be consulted to determine whether sink hole activity is likely. The United States Geological Survey is a good source of information on karst bedrock in Virginia. If an area is prone to sink hole development, site drainage should be planned to minimize the concentration of runoff. This can be accomplished by reducing the hydraulic connectivity of impervious surfaces and by the use of filter strips. Where they are required, channels or ponds should be lined.

Certain BMPs can be used in karst areas to provide infiltration opportunities over a very large area. Examples are filter strips, large bioretention facilities, and permeable pavement. These practices mimic the natural process by which rainfall enters the subsurface. Point sources of infiltration, such infiltration trenches or dry wells should be avoided (CH2M HILL, 1998).

Threatened and Endangered Species

Existing information can be obtained from surveys conducted by the Division of Natural Heritage (DNH) of the Virginia Department of Conservation and Recreation. For portions of the watershed that have not been previously surveyed, DNH's Element List can be compared to plant community information derived from previous investigations in the watershed, as well as from wetlands identification efforts. The inventory should include a list of potential threatened or endangered species.

Cultural Resources

Existing information can be obtained from the Virginia Department of Historic Resources. For potential regional (watershed) BMP sites, background research to characterize the cultural resource potential of the project area can be conducted. This research will provide a historic context for evaluating any cultural resources that might be located in the project area.

Fish and Wildlife Resources

Existing information can be obtained from the Virginia Department of Game and Inland Fisheries. This information will be useful when defining watershed goals and selecting BMPs to protect sensitive areas. In addition, fish can be a good indicator of stream health and can be used during the evaluation of effectiveness of the watershed management plan, as part of a watershed monitoring program.

Recreational Areas and Sources of Water Supply

An inventory of recreational areas and sources of water supply will also facilitate, and in some cases mandate, the goals of the watershed. This information will also be important in the selection of models that will be needed to identify sources of pollution, understand the hydrologic and hydraulic characteristics of the watershed, and evaluate alternatives to meet the watershed goals and manage water quality.

3. Conduct a Stream Inventory

Classifying the stream system within a watershed will further the understanding of its characteristics and will provide a framework for evaluating alternatives. Streams within a watershed can be inventoried based on size, order, water and habitat quality, or flow regime.

4. Identify significant environmental features in neighboring watersheds

Each subwatershed is nested within many larger watersheds. Therefore, watershed management plans for smaller watershed have to be developed within the context of the larger watershed in which they are located. Once the larger and neighboring watersheds are identified, the goals of those watersheds can be incorporated in the watershed management plan. Some of the goals that typically are incorporated in local watershed management plans include nutrient and toxic targets, such as the Tributary Strategy targets, water supply, flood protection, and waste water requirements or effluent limits (Center for Watershed Protection, 1996). In addition, large pollution sources, wildlife refuges, and sources of water supply in neighboring watersheds may also provide additional goals for the watershed management plan.

5. Identify and Quantify Existing Sources of Point and Nonpoint Source Pollution

Existing information on point sources of pollution can be obtained from the Virginia Department of Environmental Quality (DEQ). Typically, the NPDES permits for point sources will also include some monitoring requirements that can provide additional information for the watershed management efforts. Nonpoint source data can be obtained from DCR and from the local Soil and Water Conservation Districts. The local public works or engineering office can also be good sources of information on previous studies and monitoring efforts.

Watershed models are tools used to understand the cause-and-effect relationships within a watershed. Specifically, water quality models provide information on pollutant loads (from point and nonpoint sources) and their movement throughout the watershed.

Model selection is a function of the following variables:

- The goals and objectives of the watershed management plan
- The data available to describe the hydrologic and hydraulic characteristics and water quality problems in the watershed
- The regulatory requirements and other watershed specific environmental and water quality issues (including time and space scales of the issues or problems)
- The resources (cost, time, hardware and software, modeling expertise, funds) available for applying the model and implementing the recommendations developed with the model

The objectives of the model application for a watershed management plan may range from simple screening of environmental problems that require minimum data input to detailed analysis of water quantity and quality in the watershed. Detailed analysis requires more input data and usually provides information needed for the design of a specific project or for the analysis and solution of specific environmental problems. Detailed analyses are used to represent the watershed processes that affect pollution generation. However, it is not always true that detailed analyses, based on sophisticated models, provide the most accurate representation of the watershed and its environmental problems; it is best to use the least complicated model that will produce the results for appropriate decision making.

Model selection also depends significantly on the data available in the watershed. The precision of the model predictions is affected by dynamic and transient conditions, high spatial variability (mainly related to rainfall variability and land use), and differences in event conditions (such as antecedent moisture conditions, infiltration potential, local pipe or stream conditions, etc.). The data availability and the simulation complexities affect model selection by tempering the decision towards acceptance of a model that is accurate but not as precise as other more sophisticated models.
In addition to data availability issues, monitoring data and watershed responses can be highly variable. Selecting a simpler model, and accepting results that are not as precise as desired but remain accurate, is an appropriate strategy.

6. Model the Existing Hydrology and Hydraulics of the Watershed

The model selection strategy presented in the previous section also applies to hydrologic and hydraulic models.

Hydrologic models provide information on the amount of runoff that will reach the outlet of the watershed and any receiving waters. Hydraulic models estimate water surface elevations and velocities of surface water. These models are also used to characterize the drainage system in the watershed. Groundwater models represent the movement of groundwater.

The focus of the modeling of the existing characteristics of the watershed is to develop baseline information that will be used to evaluate BMP siting and sizing alternatives for meeting the watershed goals and solving drainage and flooding problems. The hydrologic and hydraulic models will also facilitate the understanding of the impact of land use, conveyances, land cover, stormwater management facilities, stream cross sections, roadway crossings, and flooding and drainage problems.

Accurate land use data will ensure accurate modeling results. Developing an updating land use and impervious cover information will facilitate the implementation of the watershed plan.

2-5.2 Planning and Developing the Watershed Management Plan

This second component will define the goals for the watershed management plan; will model future characteristics of the watershed; will develop alternatives to restore resources and meet the goals, including BMPs at the regional (watershed) level; and will produce the watershed management plan. The inventory data developed in the first component will be used as part of the decision-making process illustrated in this component.

1. Define the Goals of the Watershed Management Plan

The first step of the planning component is to define the goals that are most important to the watershed to be protected and to the stakeholder group that will be defined as part of the third component, implementation. As previously mentioned, some of the steps of the three components (inventory, planning, and implementation) need to be conducted concurrently.

A stakeholder group beginning a watershed effort needs to determine what it wants to accomplish and how it wants to use the water body being protected (water quality enhancements and quantity control). The clearer the goals, the easier it is to track progress towards meeting those goals. The goals tend to become clearer as the stakeholders proceed in their efforts. Therefore, the planning process should allow for a systematic re-evaluation of the goals at least every 3 to 5 years.

If possible, express the goals of the watershed management plan in terms of the condition of the waterbody relative to its beneficial uses, not in terms of achieving a certain level of pollutant reduction or applying a certain technology.

2. Identify and Quantify Future Sources of Point and Nonpoint Source Pollution

This step involves using the water quality models developed in the inventory component (**Section 2-5.1, step 5**) and modifying them to include future development conditions in the watershed. It is important to use future land-use information from the comprehensive plan of the municipality and any amendments or recent rezoning cases.

3. Model the Future Hydrology and Hydraulics of the Watershed

This step involves using the hydrologic and hydraulic models described in the inventory component (**Section 2-5.1, step 5**) and modifying them to include future development conditions in the watershed. It is important to use future-land use information from the comprehensive plan of the municipality and any amendments or recent rezoning cases.

4. Develop and Evaluate Alternatives to Meet the Goals and Manage Water Quality and Quantity

In order to meet the watershed goals and to solve the watershed's problems effectively, the watershed master plan should consider all feasible alternatives. These alternatives will manage water quantity and quality in the watershed. Therefore, the alternatives will address flooding, drainage, erosion, and stormwater pollution problems.

Generally, alternative solutions mitigate **flooding and drainage damages** by providing additional storage of flows, by increasing the conveyance capacity of the drainage and stream system, or by floodproofing structures at risk of flooding. Alternative solutions mitigate **erosion damages** by stabilizing stream banks using non-erosive materials and/or by redefining the meandering pattern and using the channel and floodplain to dissipate the flow energy. Alternative solutions mitigate **stormwater pollution** problems by providing structural and non-structural BMPs.

Alternatives should be evaluated by using the existing and future condition models and the information from the inventory component described in **Section 2-5.1**. A map of the watershed showing the recommended alternatives should be prepared and distributed to all stakeholders.

Each alternative, or combination of alternatives, also could be evaluated according to screening criteria that address technical, practical, environmental, economic, and political feasibility. Alternatives can be investigated in detail when they appeared to have potential to be cost-effective and satisfy all project criteria.

Selecting sites for regional (watershed-level) BMPs or flood/erosion controls involves balancing pollutant removal, runoff attenuation, environmental permitting constraints, and cost issues. The following is a typical sequence of the iterative process to be completed for each of the potential sites:

A. Identify potential regional BMP sites and sites for flood/erosion controls.

B. Field screen the sites taking into account the following:
   - drainage area
   - topography
   - existing development and projected future development
   - access and construction issues
   - wetlands constraints
   - other regulatory constraints
   - land ownership/value issues

C. Use the previously described watershed models to analyze pollutant reduction (phosphorous and total suspended solids management), flood/erosion control, and resource protection.

D. Use the inventory and models to identify performance standards for the selection, design, and location of BMPs and for the establishment of erosion, sedimentation, and flood control requirements.

5. Identify Opportunities to Restore Natural Resources

Protecting natural resources and drainage features, particularly vegetated drainage swales and channels, is desirable because of their ability to infiltrate and attenuate flows and to filter pollutants. However, this goal is often not accomplished in most developments. In fact, commonly held drainage philosophy encourages just the opposite pattern. Streets and adjacent storm sewers typically are located in the natural headwater valleys and swales, thereby replacing natural drainage functions with a completely impervious system. Runoff and pollutants generated from impervious surfaces flow directly into storm sewers with no opportunity for attenuation, infiltration, or filtration.
One method of preserving natural drainage features is to use *cluster development* to avoid disturbing major swales. Another recommended approach is to develop site plans that keep roads and parking areas higher in the landscape and *locate existing swales along back lot lines* within drainage easements.

6. Develop the Watershed Management Plan

The watershed management plan will integrate and summarize the different steps described in **Sections 2.5.1** and **2-5.2**. The plan needs to be succinct and simple to ensure that people read it. The plan needs to address the goals and problems of the watershed and should provide recommendations that are specific and implementable. Finally, the plan should include a budget and an implementation schedule, as described in **Section 2-5.3**, below.

2-5.3 Implementation of the Watershed Management Plan

A watershed management plan is effective if it is implemented. Implementation depends on the level of buy-in of the plan from the stakeholders. Stakeholders will remain interested if they are involved from the beginning and they have ways of monitoring the success of the plan.

1. Identify the stakeholders responsible for developing, implementing and updating the plan

Assemble stakeholders who are most affected early in the process. Specifically include those who use, impact and regulate the affected waterbody, and allow them to shape key decisions. Early and effective stakeholder involvement will ensure long-term accountability.

2. Define the implementation costs and who will pay for the implementation of the watershed management plan

Use uniform and consistent procedures to estimate project costs for the alternatives developed to solve the problems in each watershed. The cost should include capital costs and annual administrative, operations and maintenance costs for all the elements of the plan.

Identify the funding sources for implementation of the watershed management plan. Below is a summary of the possible funding sources:

- General obligation and revenue bonds
- Stormwater utility fees
- Land development fees
- Pro-rata share contributions
- General fund resources
- Loans and grant programs
- Special service districts and watershed improvement districts

3. Develop a watershed monitoring program

Develop a monitoring program that enables the stakeholders to objectively measure and track indicators of the watershed management plan's success. The indicators should focus on water quantity and quality issues, programmatic and socioeconomic needs, and physical and hydrologic measures.

Stormwater chemistry is fairly well understood. Therefore, chemical monitoring of stormwater outfalls will not necessarily provide valuable data. On the other hand, physical and biological monitoring and selected long-term stream monitoring stations will provide valuable information to "measure" the successful implementation of the watershed plan. If success is not achieved, the monitoring program will provide the data to make revisions to the plan. The monitoring program also will provide information to re-evaluate the watershed goals and the implementation schedule.

4. Develop an evaluation and revision process for the watershed management plan

During the implementation of the watershed management plan, it is likely that at least one of the following problems will occur:

- Monitoring indicates that the wrong problem is being solved.
- Solving one problem unmasks another problem that is more difficult to control.
- The program reaches some program or activity goals but may not be effective enough to reach the water

quality goals.

- Quantifiable objectives (e.g., pollutant load reduction or flood protection for specific storms) were set too low to solve the problem.

These unpleasant realizations typically occur because of data gaps during the development of the plan. Therefore, the watershed plan needs to include evaluation periods where aspects of the program can be revised if necessary. Watershed plan evaluations can take place every 3 to 5 years.

5. Establish and implementation schedule

Each of the steps presented in the previous sections represent groups of specific activities that make up the watershed plan. Because of the complex and developing nature of the plan, the implementation of the individual steps will occur over differing time frames and will not necessarily follow in a linear sequence but rather be in a parallel sequence.

Some activities need to be implemented quickly to ensure protection of the watershed others will take more time. Therefore, an implementation schedule typically includes a combination of immediate, short-term, and longer-term actions.

Implementation schedules need to be updated and distributed to all stakeholders regularly.

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